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(19) (CA) **APPLICATION FOR CANADIAN PATENT** (12)

(54) Dispersion Compensating Fiber

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(57) 3 Claims

Notice: This application is as filed and may therefore contain an
          incomplete specification.

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ABSTRACT OF THE DISCLOSURE

There is provided a dispersion compensating fiber comprising a center core in which a first dopant is doped
5   substantially uniformly, an outer core provided at the outer periphery of the center core, in which the first dopant is doped so as to decrease gradually toward the outer periphery, and a clad provided at the outer periphery of the outer core, in which a second dopant is doped. The second dopant of the outer
10 core is doped so that the viscosity on at least the outer periphery side of the outer core is substantially equal to the viscosity of the clad.

DISPERSION COMPENSATING FIBER

BACKGROUND OF THE INVENTION

Field of the Invention

5   The present invention relates to a dispersion compensating fiber used for a dispersion copensator, in particular, a dispersion copensator of a 1.55 μ m waveband.

Description of Prior Art

Along with the recent technical innovations, a light

10   amplifier of a 1.55 μ m waveband using an erbium doped fiber has been used practically, and its application to the distribution systems for an optical CATV etc. and the long-distance high-capacity transmission has been receiving attention. Accordingly, a demand for performing high-speed

15   transmission at a 1.55 μ m waveband by using an existing 1.3 μ m optical transmission system has increased. However, a standard 1.3 μ m single mode fiber, which has a positive wavelength dispersion of about 17 ps/nm/km at a wavelength of 1.55 μ m, requires a means for compensating the dispersion.

20   At present, a method for canceling dispersion by inserting an optical fiber having a negative wavelength dispersion which has an inverse sign of the aforesaid positive wavelength dispersion, that is, a dispersion compensating fiber into the existing 1.3 μ m transmission system has been proposed as one

25   of the most promising compensating means.

A conventional dispersion compensating fiber comprises a center core in which germanium dioxide (GeO$_2$) is doped substantially uniformly (in other words, which has a substantially uniform difference in specific refractive

30   index), an outer core provided at the periphery of the center core, in which GeO$_2$ is doped so as to decrease gradually toward the outer periphery (in other words, whose difference in specific refractive index decreases gradually toward the outer

periphery), and a clad provided at the periphery of the outer core, in which fluorine (F) is doped.

For one example of such dispersion compensating fibers, FIG. 4 shows the dopant concentration in the radial direction as a difference in specific refractive index in which the refractive index of silica glass is a reference (hereinafter referred simply to as a difference in specific refractive index), and FIG. 5 shows the distribution of difference in specific refractive index in the radial direction.

For the aforementioned dispersion compensating fiber, the center core has a difference in specific refractive index $\Delta [GeO_2]$ of +1.8%, and the clad has a difference in specific refractive index $\Delta [F]$ of -0.4%. Therefore, the difference in specific refractive index Δ between the center core and the clad is 2.2%. The difference in specific refractive index Δ $[GeO_2]$ of the outer core is almost the same as that of the center core at the interface with the center core and almost the same as that of the clad at the interface with the clad.

It is preferable in view of an insertion space and other problems that a dispersion compensating fiber inserted into the existing 1.3 μ m transmission system be as short as possible. Accordingly, the need for a dispersion compensating fiber having a large negative wavelength dispersion as per length has increased.

In general, the dispersion compensating fiber can increase the negative wavelength dispersion by increasing the difference in specific refractive index Δ between the center core and the clad. Also, the dispersion compensating fiber has an outer core in which the specific refractive index decreases gradually toward the outer periphery. For this reason, the dispersion compensating fiber has no problem of the increase in structural defect loss caused when the difference in specific refractive index between the core and

the clad is increased in the ordinary optical fiber.

Since the refractive index of the outer core is decreased gradually toward the outer periphery in the aforementioned dispersion compensating fiber, however, a portion having a
5   lower viscosity than that of the clad is produced in the outer core in the drawing process. As a result, the aforementioned dispersion compensating fiber has a disadvantage that tensions are concentrated at that portion and residual stresses are generated so that a polarization mode dispersion is produced,
10   and therefore it is not suitable for practical use. This polarization mode dispersion has no adverse effect when the dispersion compensating fiber is used for the ordinary systems, but it is attributable to an increase in composite second order when it transmits analog picture signals for optical CATV, etc.
15   When the composite second order increases, there arise problems of an increase in bit error rate and generation of polarization dispersion loss (PDL). Therefore, the development of a dispersion compensating fiber which does not produce composite second order, that is, which has no
20   polarization mode dispersion and has a large negative wavelength dispersion with a short length has been urged.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a
25   dispersion compensating fiber which produces no polarization mode dispersion and has a large negative wavelength dispersion with a short length.

To achieve the above object, the present invention provides a dispersion compensating fiber comprising a center
30   core in which a first dopant is doped substantially uniformly, an outer core provided at the outer periphery of the center core, in which the first dopant is doped so as to decrease gradually toward the outer periphery, and a clad provided at

the outer periphery of the outer core, in which a second dopant is doped, the second dopant of the outer core is doped so that the viscosity on at least the outer periphery side of the outer core is substantially equal to the viscosity of the clad.

5   Preferably, the first and second dopants are germanium dioxide and fluorine, respectively.

In the present invention, in order to avoid a problem of the increase in structural defect loss, the difference in specific refractive index between the center core and the clad, which substantially determines the magnitude of the negative wavelength dispersion, is made large, whereby the reflactive index of the outer core is gradually decreased toward the outer periphery. In this case, a portion having a lower viscosity than that of the clad is not produced in the outer core of the dispersion compensating fiber in the drawing process, so that tensions do not concentrate at this portion, and residual stresses are not generated. Therefore, the manufactured dispersion compensating fiber has no possibility of generating a polarization mode dispersion caused by the above-described reason, and in turn a composite second order.

The above and other objects, features, and advantages of the present invention will be more apparent in the following detailed description with reference to the accompanying drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a dispersion compensating fiber in accordance with the present invention;

FIG. 2 is a dopant concentration distribution view showing dopant concentrations in the radial direction of the dispersion compensating fiber in accordance with the present invention as a difference in specific refractive index in which the refractive index of silica glass is the reference;

FIG. 3 is a distribution view for difference in specific refractive index showing differences in specific refractive index in the radial direction of the dispersion compensating fiber in accordance with the present invention;

5   FIG. 4 is a dopant concentration distribution view showing dopant concentrations in the radial direction of the dispersion compensating fiber in accordance with the comparative example as a difference in specific refractive index in which the refractive index of silica glass is the reference; and

10   FIG. 5 is a distribution view for difference in specific refractive index showing differences in specific refractive index in the radial direction of the dispersion compensating fiber in accordance with the comparative example.

15   **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

An embodiment of the present invention will be described in detail with reference to the drawings.

As shown in FIG. 1, a dispersion compensating fiber comprises a center core 1 which has a substantially uniform
20   difference in specific refractive index, an outer core 2 provided at the periphery of the center core 1, whose difference in specific refractive index decreases gradually toward the outer periphery, and a clad 3 provided at the periphery of the outer core 2, in which fluorine is doped.

25   The dispersion compensating fiber has a dopant concentration and difference in specific refractive index shown in FIGS. 2 and 3, respectively, in the radial direction. FIG. 2 shows dopant concentrations in the radial direction as a difference in specific refractive index in which the
30   refractive index of silica glass is the reference, and FIG. 3 shows differences in specific refractive index in the radial direction. In the figures, reference numeral 5 denotes a portion corresponding to the center core 1, 6 denotes a portion

corresponding to the outer core 2, and 7 denotes a portion corresponding to the clad 3. These are true in FIGS. 4 and 5 as well.

5 The aforementioned dispersion compensating fiber was manufactured in the following way. First, a GeO_2 doped silica porous base material, which constitutes the center core and the outer core, was manufactured by the VAD method. It is so far known that the dope amount of fluorine changes depending on the soot density when the silica porous base material is 10 sintered in the SiF_4 atmosphere. In manufacturing the silica porous base material, therefore, control was carried out so that the soot density at the portion corresponding to the outer core decreases toward the outside in the radial direction by controlling the burner position, oxygen gas quantity, hydrogen 15 gas quantity, etc. By dehydrating and sintering the porous base material thus manufactured under the conditions given in Table 1, a core rod in which an outer core is formed outside a center core was obtained.

20 <div align="center">Table 1</div>

	Atmosphere	Temp.	Insertion speed
Dehydration	He gas to which 2 vol% Cl_2 is added	1000°C	4 mm/min
Sintering	He gas to which 4 vol% SiF_4 and 1 vol% Cl_2 is added	1400°C	4 mm/min

Next, the core rod was extended into an outside diameter of 12 mm, and hydrofluoric acid etching was applied to the

surface thereof. After that, a clad consisting of fluorine doped silica glass of $\Delta[F] = -0.4\%$ was formed at the periphery by the externally attaching method to manufacture a porous base material for optical fiber. By dehydrating and sintering the porous base material for optical fiber under the conditions given in Table 2, an optical fiber base material was obtained.

Table 2

	Atmosphere	Temp.	Insertion speed
Dehydration	He gas to which 2 vol% Cl_2 is added	1000℃	4 mm/min
Sintering	He gas to which 12.7 vol% SiF_4 is added	1400℃ ·	4 mm/min

The resultant optical fiber base material has a difference in specific refractive index distribution as shown in FIG. 3. The dopant concentration is as shown in FIG. 2. As seen from the figure, the difference in specific refractive index Δ [GeO_2] of the center core 1 is +2.0%, the difference in specific refractive index $\Delta[F]$ of the clad 3 is -0.2%, the difference in specific refractive index Δ [GeO_2] at the outer periphery of the outer core 2 is +0.3%, and the difference in specific refractive index $\Delta[F]$ at the inner periphery of the clad 3 is -0.3%. It is found that both of GeO_2 and F reduce the viscosity of silica glass. If GeO_2 and F are doped so that the differences in specific refractive index at the outer periphery of the outer core 2 and the inner periphery of the clad 3 ensures the relationship of Δ [GeO_2]$/\Delta[F] = -3$, the viscosity of the outer core 2 and clad 3 becomes equal in the drawing process

of optical fiber. That is to say, if the equal amounts of GeO_2
and F in difference in specific refractive index are added to
silica glass, F reduces the viscosity of silica glass by a
factor of three over GeO_2. The contributions of GeO_2 and F to
5   the difference in specific refractive index in each core, Δ
$[GeO_2]$ and $\Delta[F]$, were determined by comparing the refractive
index distribution of an optical fiber material obtained by
sintering, in an atmosphere containing no SiF_4, the porous base
material for optical fiber manufactured under the same
10   conditions as those described above.

A dispersion compensating fiber was drawn from the optical
fiber base material thus manufactured, and a coating layer of
ultraviolet curing type resin was immediately applied. Thus,
three dispersion compensating fibers with an outer core
15   diameter of 2.5 μ m, a clad diameter of 125 μ m, a coating
diameter of 240 μ m, and a length of about 10 km were
manufactured. The polarization mode dispersions of the
manufactured dispersion compensating fibers were measured by
Jones matrix method, with the result of 0.089 $ps/km^{-1/2}$, 0.123
20   $ps/km^{-1/2}$, and 0.108 $ps/km^{-1/2}$, all of them being approximately
0.1 $ps/km^{-1/2}$. These values are equivalent to the polarization
mode dispersion (0.099 $ps/km^{-1/2}$) of a standard 1.3 μ m single
mode fiber.

As a comparative example, three conventional dispersion
25   compensating fibers were manufactured, which comprises a
center core portion 5 in which GeO_2 is doped substantially
uniformly in the radial direction, an outer core portion 6
provided at the outer periphery of the center core portion 5,
in which GeO_2 is doped so as to decrease gradually toward the
30   outer periphery, and a clad portion 7 provided at the outer
periphery of the outer core portion 6, in which fluorine is
doped, as shown in FIG. 4. The difference in specific
refractive index $\Delta[GeO_2]$ of the center core portion 5 was +1.8%,

and the difference in specific refractive index Δ [F] of the clad portion 7 was -0.4%. Therefore, the difference in specific refractive index Δ between these portions 5 and 7 was 2.2%. Its distribution of refractive index was as shown in

5   FIG. 5, being almost the same as the distribution of refractive index of the dispersion compensating fiber manufactured in the working example shown in FIG. 3.

The polarization mode dispersions of the dispersion compensating fibers thus obtained were measured by Jones matrix

10   method, with the result of 0.790 ps/km$^{-1/2}$, 0.420 ps/km$^{-1/2}$, and 0.334 ps/km$^{-1/2}$. These values were considerably larger than the polarization mode dispersion (0.099 ps/km$^{-1/2}$) of a standard 1.3 μ m single mode fiber.

WHAT IS CLAIMED IS:

1. A dispersion compensating fiber comprising a center core in which a first dopant is doped substantially uniformly, an outer core provided at the outer periphery of said center core, in which said first dopant is doped so as to decrease gradually toward the outer periphery, and a clad provided at the outer periphery of said outer core, in which a second dopant is doped,

characterized in that, said second dopant of said outer core is doped so that the viscosity on at least the outer periphery side of said outer core is substantially equal to the viscosity of said clad.

2. A dispersion compensating fiber according to claim 1, wherein said first dopant is germanium dioxide.

3. A dispersion compensating fiber according to claim 1, wherein said second dopant is fluorine.
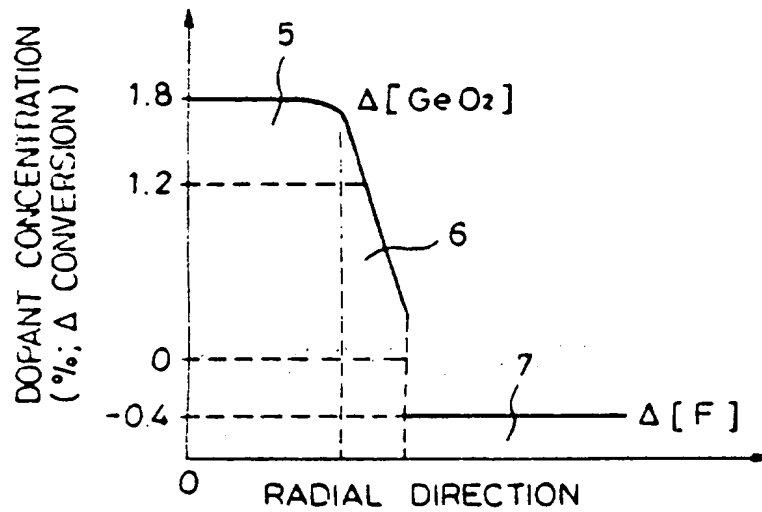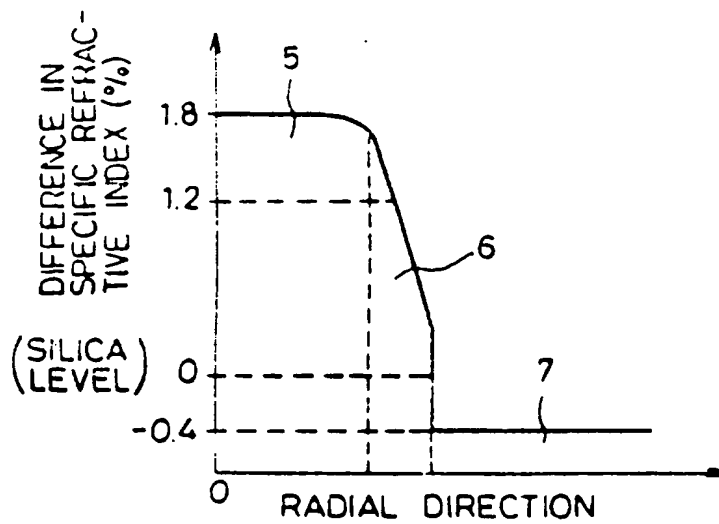
FIG. 1

3

1

2
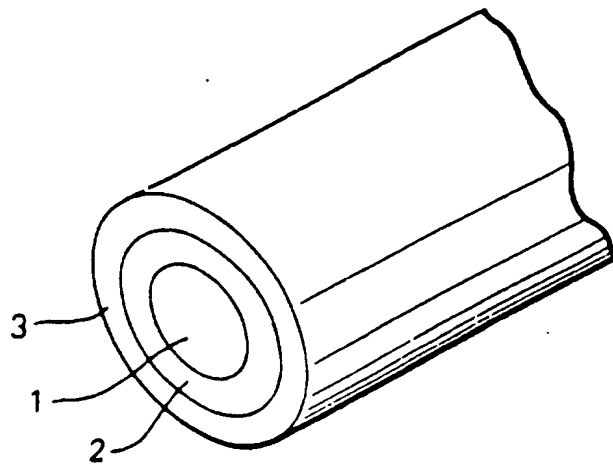
F I G. 2
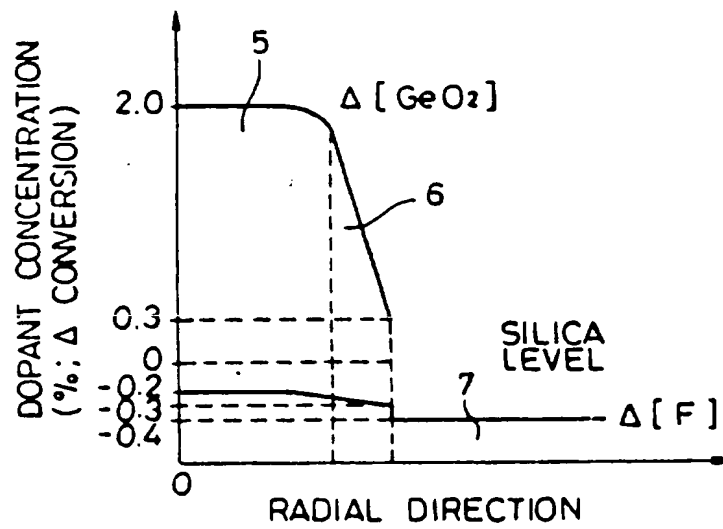
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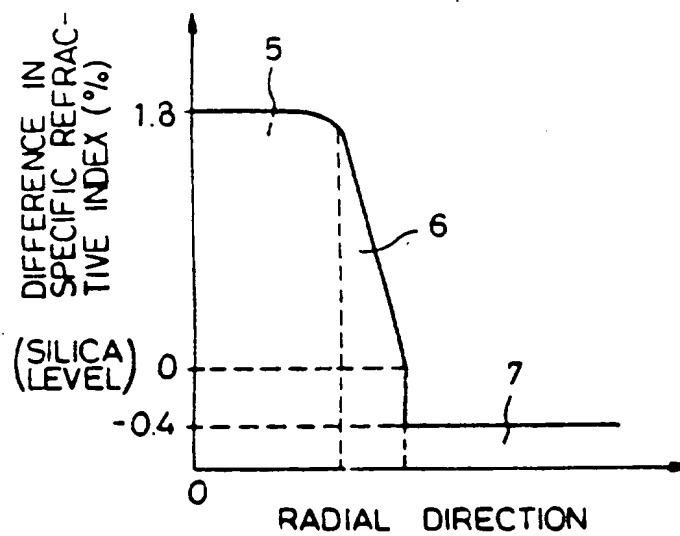
F I G. 4

F I G. 5

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